AD 630 989

SHIPBOARD INTERFERENCE SIMULATOR

ANALOG COMPUTER-LIKE DEVICE DEVELOPED AT NEL REPRODUCES FREQUENCIES DERIVED FROM INTERMODULATION BETWEEN COMBINED TRANSMITTER FUNDAMENTALS

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PROBLEM

Develop means to reduce the generation of interference products in the shipboard communication system in order to optimize communications effectiveness. Conduct studies, analyses, experiments, and applied research to devise means and techniques which can be applied to minimize the intensity of electrical noise and interference products generated by ship's equipment or by nonlinear action of portions of the ship's hull. Specifically, develop a simulator to demonstrate the seriousness of the intermodulation problem aboard ship, and to aid in the prediction of possible interfering frequencies for a given set of transmitter fundamentals.

RESULTS

1. A shipboard interference simulator has been designed which accurately reproduces the potential frequencies of interference derived from the intermodulation between any combination of simultaneous transmitter fundamental frequencies up to a total of 10. The relationship of interference-signal magnitudes is in reasonable agreement with similar signals actually measured aboard ship.

2. The simulator has proved its worth as an aid in demonstrations of intermodulation interference before Naval personnel concerned with shipboard communications problems.

3. The simulator represents an analog computer with which detailed knowledge of intermodulation phenomena can be increased. It is especially valuable when more than the classic two fundamental signals are on together.

RECOMMENDATIONS

1. Make available to representative elements of the Fleet a number of simulators with 10 or more oscillators each.

2. Conduct a realistic evaluation to determine the acceptance or worth of this real-time technique as a means of improving Fleet communications.

3. Employ simulators in which the oscillators are on operational transmit frequencies to determine and avoid self-generated interference aboard ship.

ADMINISTRATIVE INFORMATION

Work was performed from January 1964 to December 1964 under SS 296 0014, Task 11034 (NEL J51061) and the report was approved 12 January 1966.

The authors wish to acknowledge the contributions of J. D. Campbell, of the Antennas Division, during the construction and measurement phases of the work.

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INTRODUCTION

Assume that a signal of frequency f_1 is applied to an electrically nonlinear element. It will be found that the output of this nonlinear element will contain not only fundamental frequency f_1 but also frequencies harmonically related to f_1; that is, frequencies $2f_1$, $3f_1$, $4f_1$ .... If now two fundamental signals of different (nonharmonically related) frequencies f_1 and f_2 are applied to the nonlinear element, it will be found that the output from the nonlinear element contains not only harmonic frequencies $2f_1$, $3f_1$, $4f_1$ ...., $2f_2$, $3f_2$, $4f_2$ ....., but also frequencies which are related to the fundamentals in the following manner:

$$f_1 \pm f_2 \qquad 3f_1 \pm f_2$$

$$2f_1 \pm f_2 \qquad f_1 \pm 3f_2$$

$$f_1 \pm 2f_2 \qquad 3f_1 \pm 2f_2$$

$$2f_1 \pm 2f_2 \qquad 2f_1 \pm 3f_2$$

These frequencies are called intermodulation products, or cross products. The coefficients of the fundamental signals are always integral. One would not, for example, find a signal of frequency $1.1f_1$ at the output of the nonlinear element. The sum of the absolute values of the coefficients of the fundamentals is the order of the intermodulation products, so that f_1+f_2 and f_1-f_2 are both second-order products, while (assuming for the moment, a third fundamental, f_3) $f_1+f_2+f_3$, $f_1-f_2-f_3$, $2f_1+f_3$, are all third-order products.

If the nonlinear element has a voltage-current characteristic curve which is asymmetrical with respect to the origin, all orders of intermodulation products will appear at the output, while if the characteristic curve is symmetrical with respect to the origin, only odd-order products will be generated by the element. Diodes, transistors, thermistors, and most other nonlinear devices are asymmetrical, and therefore generate intermodulation products of even

order as well as odd order. However, it is found that in the real world a number of naturally occurring nonlinear elements have a very high degree of symmetry so that the even-order products, though present at the output, are considerably lower in magnitude than the odd-order products. (A very slight departure from perfect symmetry is sufficient to cause even-order products to be generated.)

Several studies, notably those performed by the Illinois Institute of Technology Research Institute (IITRI) under contract with the U. S. Navy Electronics Laboratory, have shown that there are a number of naturally occurring nonlinear junctions on shipboard. They occur at riveted and bolted metallic junctions, at areas of rust and corrosion on cable armor, and at various other points above deck, that is, in the environment external to the ship's transmitting and receiving system. There are, of course, nonlinearities inherent in the transmitting and receiving systems; however, intermodulation-product generation within these systems can be reduced to a tolerable level by proper filtering and other techniques, and they are not properly a matter of discussion in this report. Furthermore it is known that when current densities in a ferromagnetic material are high, the material is nonlinear and can generate intermodulation products.

If fundamental currents in the ship's hull flow through one of these naturally occurring nonlinearities, intermodulation products are generated. If these signals are radiated from a portion of the ship's structure, one or more of the intermodulation products may fall on one of the ship's receiving frequencies, thus masking an incoming message. The question of the relative contributions to intermodulation interference with the ship's receiving system by nonlinear junctions and nonlinear ferromagnetic materials is a difficult one and has not been resolved. It is known for certain that junctions do contribute to interference, but it is not known whether current densities in the ship's hull attain values high enough to generate a significant intermodulation product within the steel. The important thing for us to know at the moment, though, is that intermodulation products are generated in the ship's hull and that these products do interfere with the ship's receiving system. Furthermore,

nonlinear elements which contribute to interference on shipboard exhibit a high degree of symmetry, as evidenced by the fact that even-order products are in general considerably weaker than odd-order products.

Aboard ship the basic source of the fundamental signals requisite to intermodulation-product generation in the nonlinear elements is the ship's own transmitting system. (Less commonly, an interference-contributing fundamental signal may come from without the immediate shipboard environment. For example, shore television station frequencies have mixed with a ship's transmitting frequency, generating interference on the ship while some distance at sea. However, since little or no control can be exerted on these external sources, we will not consider them in this report.)

The number of second-order intermodulation products theoretically possible with seven fundamental signals is about 50, including the harmonics. The number of fifth-order products is greater than 3000. The number of products rises very rapidly with increasing order. With seven fundamentals the number of seventh-order products is probably in the hundreds of thousands and the number of ninth-order products in the millions.

Thus, it can be seen that as the outgoing traffic and the transmitter power increase, thus generating higher and higher orders of cross products, the problem of intermodulation interference becomes ever more serious.

These considerations raise a number of questions. For example, with seven fundamental signals the number of intermodulation products of orders two through nine is in the millions, but what is the approximate density of these products within the 2-to-30-Mc/s frequency range for a given set of seven transmitting frequencies? Which fundamental frequencies of a given particular set contribute to a specific interfering intermodulation signal? There are a number of other questions, the answers to which may aid in the reduction of intermodulation interference. Some of these questions can be answered in part or in full with the aid of a computer, but this is an expensive and time-consuming procedure.

NEL SHIPBOARD INTERFERENCE SIMULATOR

Consideration of the manner in which this interference is generated aboard ship leads naturally to the idea of simulating this process in the laboratory; that is, of bringing two or more fundamental signals together and mixing them in a nonlinear element, thus generating precisely those intermodulation frequencies generated in the real world, and then feeding these signals to a radio receiver to determine frequencies, average number per unit of frequency range, and other information.

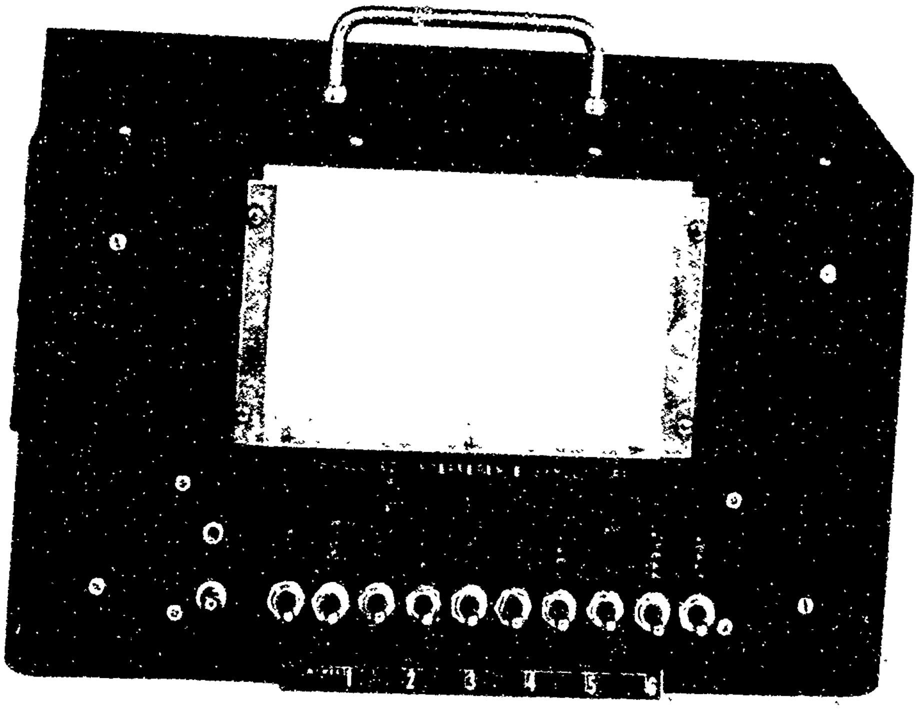
Besides its use as a laboratory tool, it was envisioned that a device capable of this simulation would have application in demonstrating the magnitude of the problems involved in intermodulation interference. Furthermore, it was hoped that eventually it might be used aboard ship in the real-time prediction of interference on a given specific receiving frequency from a known combination of simultaneous transmitter frequencies.

As mentioned, basically what was needed was a source of fundamental signals, which signals, when applied simultaneously to a nonlinear device, would provide intermodulation products of the fundamentals. Practical considerations involving the output voltage of inexpensive commercial sources of sinusoidal signals and signal levels required for efficient generation of intermodulation products in nonlinear devices dictated that an amplifier be used to raise the signal levels available to the input of the nonlinear mixing device.

The device, which has been called a Shipboard Interference Simulator (SIS) (fig. 1) is thus seen to consist of five main divisions -- the fundamental-signal sources, an electrical combining network, an amplifier, a nonlinear mixing device, and a power supply. The five major divisions are combined in a metal chassis and cabinet.

The number of fundamental signals required may vary from one application to another. Capacity of 10 fundamental signals was considered desirable for the SIS built here at NEL.

A



B

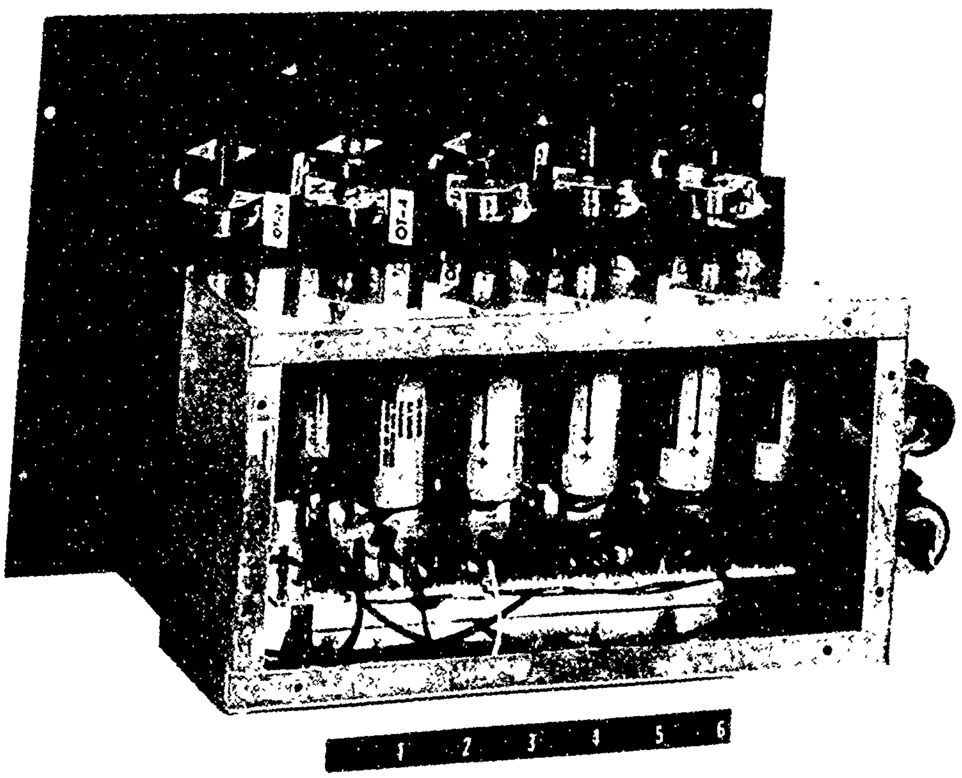


Figure 1. Shipboard interference simulator -- front view with case (A), rear view with case removed (B), and bottom view with case removed (C).

C

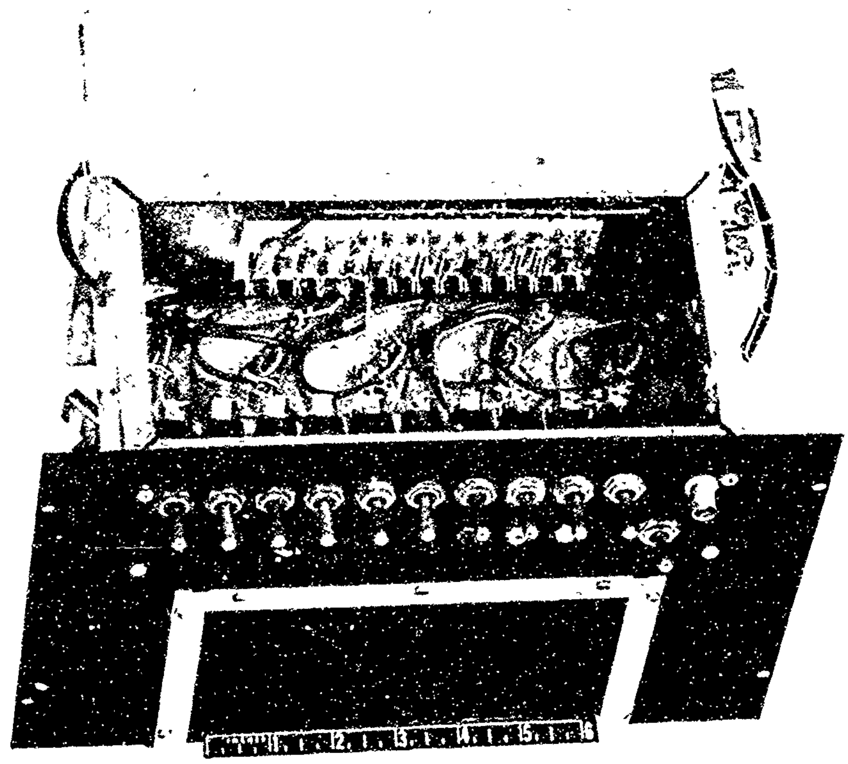


Figure 1 (Continued)

OSCILLATORS

Size and power-requirement considerations indicated that the fundamental-signal source should be a transistor oscillator. Frequency-stability considerations indicated that the oscillator should be crystal controlled.

The oscillators chosen are manufactured by the International Crystal Manufacturing Company of Oklahoma City, Oklahoma. In order to cover the entire frequency range from 2 to 30 Mc/s, three models were required -- the OT-3 (2 to 12 Mc/s), the OT-4 (10 to 20 Mc/s), and the OT-24 (20 to 40 Mc/s).

The crystals are ordered separately, and their frequency, of course, determines the specific output frequency of the oscillator. It was felt that the frequency tolerance and stability, and the power requirements of the oscillators fulfilled the requirements of an experimental model of the SIS. Furthermore, the oscillators are small, relatively inexpensive, and readily available (table 1 and figs. 2 and 3).

TABLE 1. OSCILLATOR AND CRYSTAL TYPES, INTERNATIONAL CRYSTAL MANUFACTURING COMPANY, OKLAHOMA CITY, OKLAHOMA

TABLE 1-A. OSCILLATOR TYPES

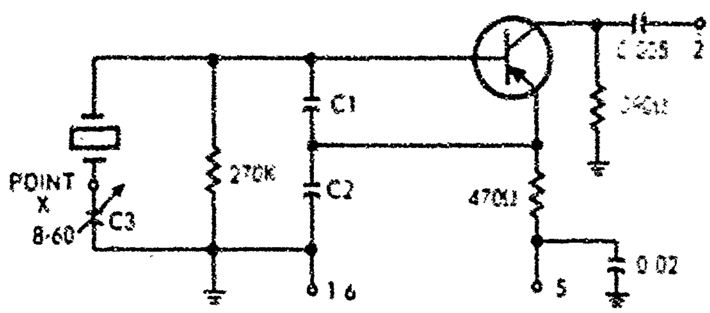
<table>
<tr><th>TYPE</th><th>RANGE</th><th>CRYSTAL TYPE</th><th>TEMPERATURE TOLERANCE, -40°F TO 150°F</th><th>PRICE ($)*</th><th>OUTPUT</th></tr>
<tr><td>OT-1</td><td>70 - 200 KC/S</td><td>CY-13T</td><td>±0.015%</td><td rowspan="4">7.00</td><td rowspan="4">1 V MIN ACROSS 470Ω</td></tr>
<tr><td>OT-2</td><td>200 - 5000 KC/S</td><td rowspan="3">CY-6T</td><td>200 - 600 KC/S ±0.01%
600 - 5000 KC/S ±0.0035%</td></tr>
<tr><td>OT-3</td><td>2 - 12 MC/S</td><td rowspan="3">±0.0035%</td></tr>
<tr><td>OT-4</td><td>10 - 20 MC/S</td></tr>
<tr><td>OT-24</td><td>20 - 40 MC/S</td><td>CY-7T</td><td>9.10</td><td>0.2 V MIN ACROSS 51Ω</td></tr>
</table>

*LESS CRYSTAL

TABLE 1-B. CRYSTAL PRICES

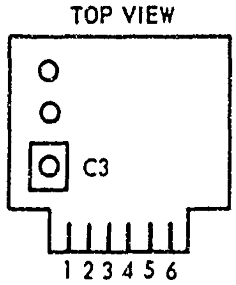
FREQUENCY	PRICE ($)
70 – 99 KC/S	22.50
100 – 200 KC/S	15.00
200 – 499 KC/S	12.50
500 – 849 KC/S	22.50
850 – 999 KC/S	15.00
1.000 – 1.499 MC/S	9.80
1.500 – 2.999 MC/S	6.90
3.000 – 10.999 MC/S	4.90
11 – 40 MC/S	6.90

It was found that the harmonic output of the OT-3 and OT-4 oscillators was very high. The second harmonic and a number of higher harmonics as well were frequently within 1 or 2 dB of the fundamental signal level. Although the presence of strong harmonics would not contribute any new intermodulation products in the mixing process, it was deemed desirable for reasons explained in PERFORMANCE TESTS to reduce the level of the harmonics. A few minor changes in the OT-3, -4, and -24 types resulted in the circuits



OSCILLATOR TYPE	C1	C2
OT-1	5000	5000
OT-2	500	2000
OT-3	150	200
OT-4	100	100

TOP VIEW

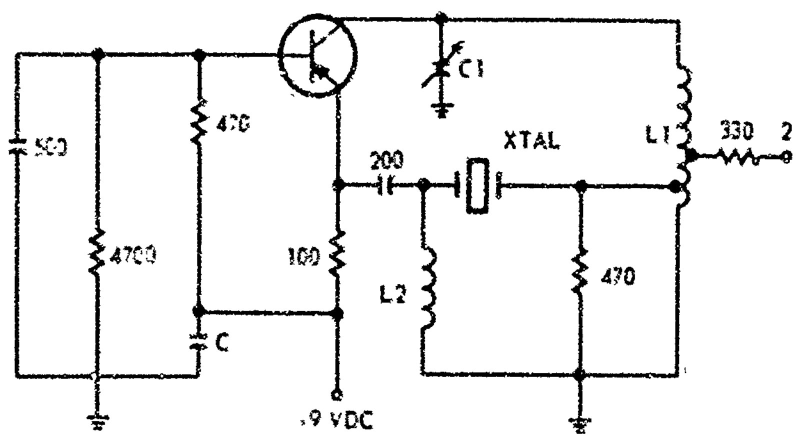


CONNECTIONS

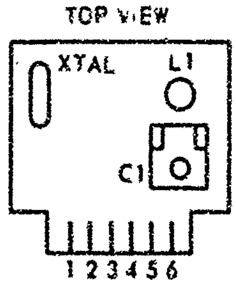
1 GROUND AND -9 VDC
2. OUTPUT
3 NO CONNECTION
4 NO CONNECTION
5 +9 VDC
6. GROUND AND -9 VDC

OUTPUT WAVE SHAPE IS NONSINE (SQUARE TO PEAKED) SINE WAVE VOLTAGE MAY BE TAKEN AT POINT X ACROSS C3. ANY LOAD CAPACITANCE AT THIS POINT WILL CHANGE THE FREQUENCY AND C3 WILL HAVE TO BE READJUSTED ACCORDINGLY.

Figure 2. OT-1, -2, -3, and -4 crystal oscillators (information from manufacturer's literature).



TOP VIEW



CONNECTIONS

1 GROUND AND -9 VDC
2 OUTPUT
3 NO CONNECTION
4 NO CONNECTION
5 -9 VDC
6 GROUND AND -9 VDC

TUNING: INSERT CRYSTAL, APPLY VOLTAGE, AND TUNE CAPACITOR C1, STARTING AT MINIMUM CAPACITY. CHECK OSCILLATOR USING AN EXTERNAL INDICATOR CONNECTED AT PIN 2. ADJUST C1 FOR PEAK OUTPUT AND THEN INCREASE CAPACITANCE TO REDUCE OUTPUT 25 PERCENT. SWITCH BATTERY ON, THEN OFF, TO INSURE PROPER CRYSTAL STARTING.

RF INDICATOR

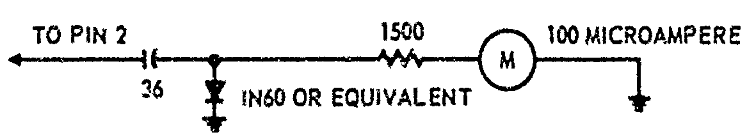


Figure 3. OT-24 crystal oscillator (information from manufacturer's literature).

shown in figure 4. This configuration was used to take advantage of the frequency selectivity of the crystal. It reduced the output of the fundamental signal somewhat but at the same time reduced the harmonics to a level 30 or 40 dB below the fundamental. The OT-3 and -4 oscillators are zeroed in to the crystal frequency by adjusting capacitor C3.

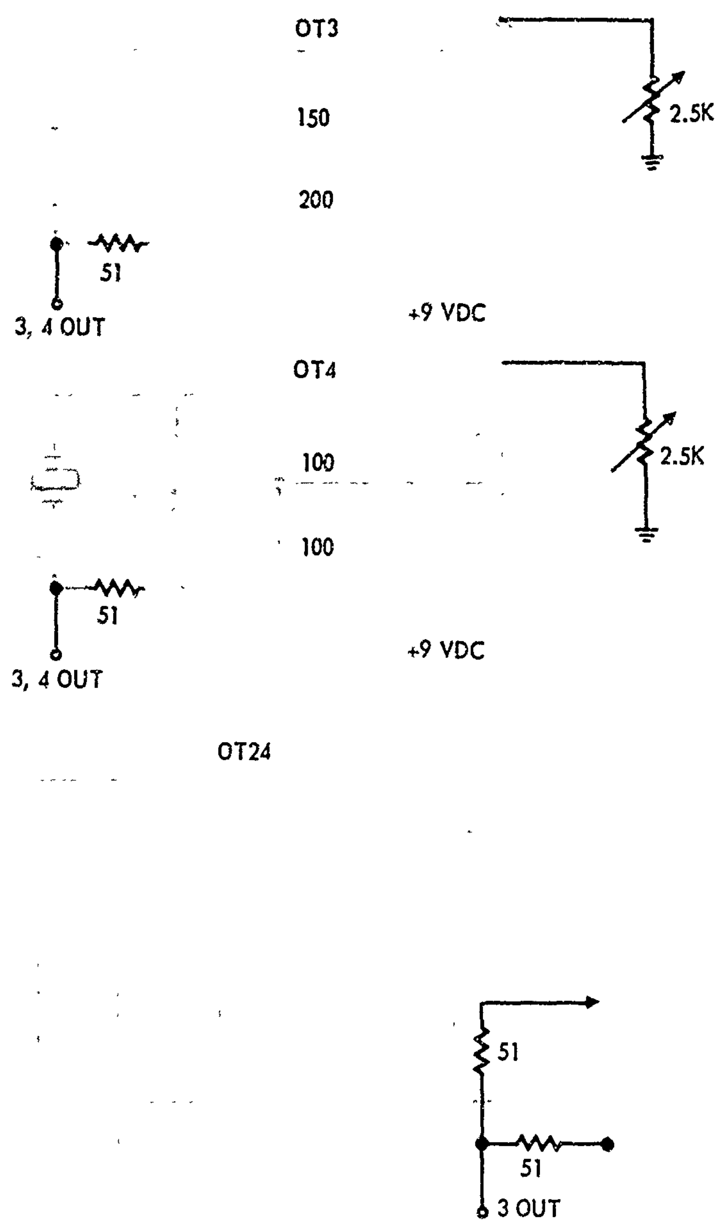


Figure 4. Modified OT-3, -4, and -24 crystal oscillators.

The second-harmonic output of the OT-24 oscillator was found to be approximately 30 dB below the fundamental level. Another factor favoring low-level harmonics at point B of figure 5 is that the gain of the amplifier falls off rapidly above 30 Mc/s. The lowest frequency possible for a second harmonic from an OT-24 is 40 Mc/s. At this frequency and at all higher frequencies the gain of the amplifier

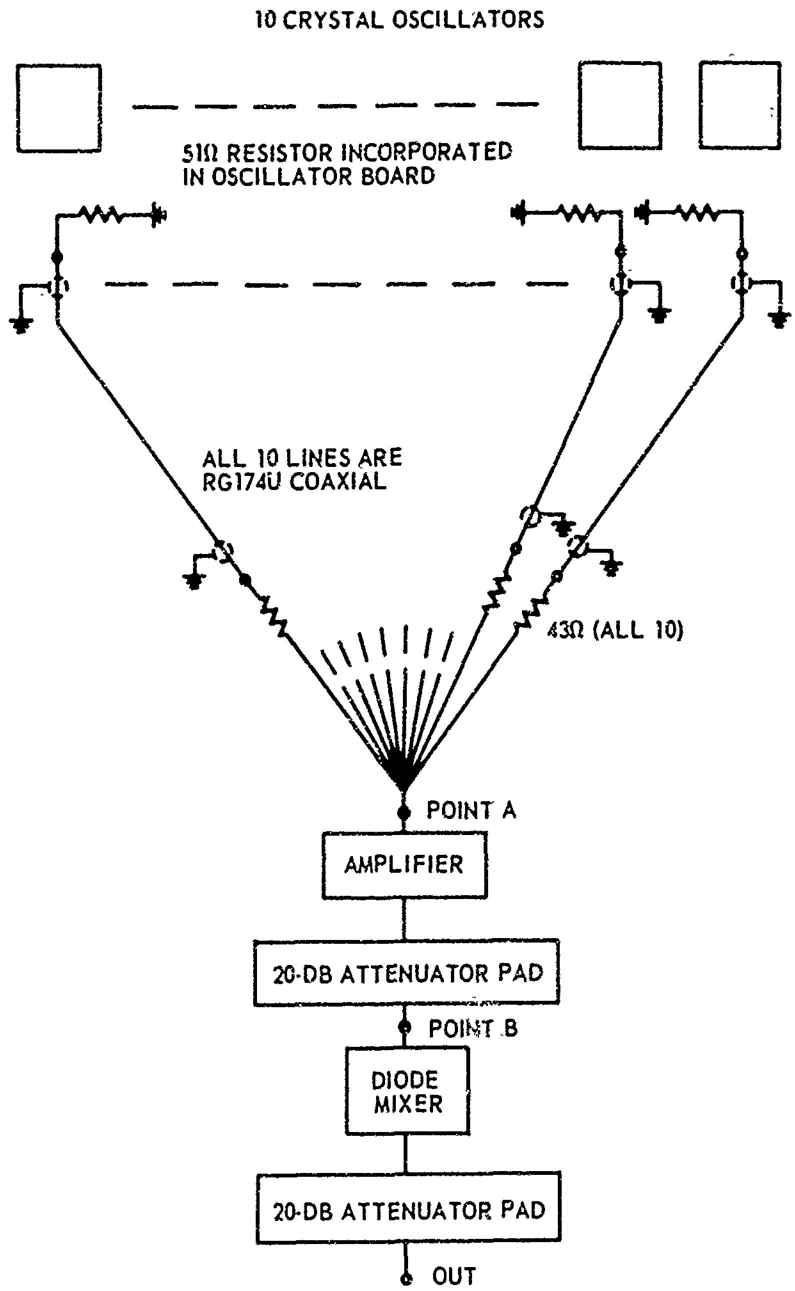


Figure 5. Combining network.

is very poor. There is no provision for zeroing in to the crystal frequency in the OT-24. The frequency tolerance is advertised as ±0.0035 percent and all OT-24 oscillators tested were within this tolerance.

The starting capabilities of the three types of oscillator are good, but the OT-24 must be properly adjusted by the tuning procedure described in figure 3. Output of all

three types, as modified, is taken off pin 3.

The voltage output of a particular oscillator board varies with the particular crystal chosen. Furthermore, the outputs of two different oscillator boards, each tested in turn with the same crystal, are found to vary. Also, the output of the OT-3 is in general greater than the output of the OT-4, which in turn has a greater output than the OT-24. It was desired to equalize the outputs of the oscillators at point B of figure 5 to 30 millivolts across 50 ohms. To compensate for the variation in output among the oscillators and for the varying gain of the amplifier over the 2-to-30-Mc/s range, potentiometers were installed in the oscillators as in figure 4. The output of the oscillator is varied by means of the potentiometer. Another modification of the oscillators is the addition of the 51-ohm resistor to ground at the output. The potentiometer and the shunt resistors are physically incorporated in the oscillator board.

COMBINING NETWORK

The primary function of the combining network is to bring the signals from all the oscillators to the input of the amplifier. The receptacles which accept the plug-in oscillators can be either Amphenol 143 or Cinch type 250 six-contact connectors. The network must be frequency insensitive; must provide sufficient isolation between oscillators so that there is no uncontrollable interaction between them; must present a 50-ohm termination to each end of the coaxial line which was considered desirable between the Amphenol 143 (or Cinch type 250) connector and the 43-ohm resistor; and must be completely symmetrical in the sense that any of the three types of oscillators may be inserted in any of the 10 chassis receptacles.

The requirement that the combining network be frequency-insensitive indicates the use of resistors. The resistive network shown in figure 5 provides about 25 dB of isolation between the outputs of any two oscillators. Tests proved this to be sufficient (see PERFORMANCE TESTS). There was negligible interaction between oscillators. To illustrate what is meant by negligible interaction

between oscillators, consider two oscillators with no isolation between them. The harmonics from one oscillator feed into the second oscillator, and the output from the common point contains intermodulation products of the two fundamental frequencies. The presence of these products is expected, since the transistors within the oscillators are themselves nonlinear, but the amplitudes of the products do not bear a consistent relationship to each other. Thus a thirteenth-order product may be at a higher level than a third-order product for this oscillator combination. For another combination there will be a different relationship between the amplitudes of various orders of products. It was found that if both pins 1 and 6 of the oscillator receptacles were not grounded with the shortest possible connection to ground, the same phenomenon occurred. This is not a desirable situation.

The physically longest connection in the network lies between the connector which receives the plug-in oscillator and the 43-ohm resistor in each leg. In an effort to prevent interaction between various legs of the combining network and thus actually enjoy the full 25 dB of isolation between oscillators, a 50-ohm RG174/U coaxial line was used between these points. The 43-ohm resistor in series with a value of 9 ohms for the other oscillator legs and amplifier in shunt gives a 52-ohm impedance at one end, and the 51-ohm resistor to ground provides the correct impedance at the other end.

AMPLIFIER

Studies of shipboard interference have indicated that intermodulation products of order higher than the ninth probably do not contribute significantly to shipboard interference. (This ninth-order value assumes two, and only two, fundamental signals. In this report, unless noted otherwise, a given-order product refers to the combination of only two fundamental signals.) A minimum goal of ninth-order cross-product generation in the mixing device was set. Most of the signals had too low a value at point A of figure 5 to ensure generation of ninth-order products with

the particular mixing device chosen. A broadband transistor amplifier is used to raise the level of these signals. The amplifier circuit diagram is shown in figure 6. The voltage gain of this amplifier over the 2-to-30-Mc/s range varies between about 25 and 30 dB. The variation in gain is accounted for in the adjustment of the potentiometers of the individual oscillators so that the outputs of all the signals from the amplifier are equalized at 30 millivolts across 50 ohms as mentioned previously. The bias voltage requirements of the amplifier are +25 and -4 volts, and the amplifier draws about 30 milliamperes from each bias supply. It will be seen in PERFORMANCE TESTS that even if the amplifier does generate intermodulation products because of the nonlinearities inherent in the transistors, the mixing unit is a more efficient generator and thus is actually the controlling nonlinear element.

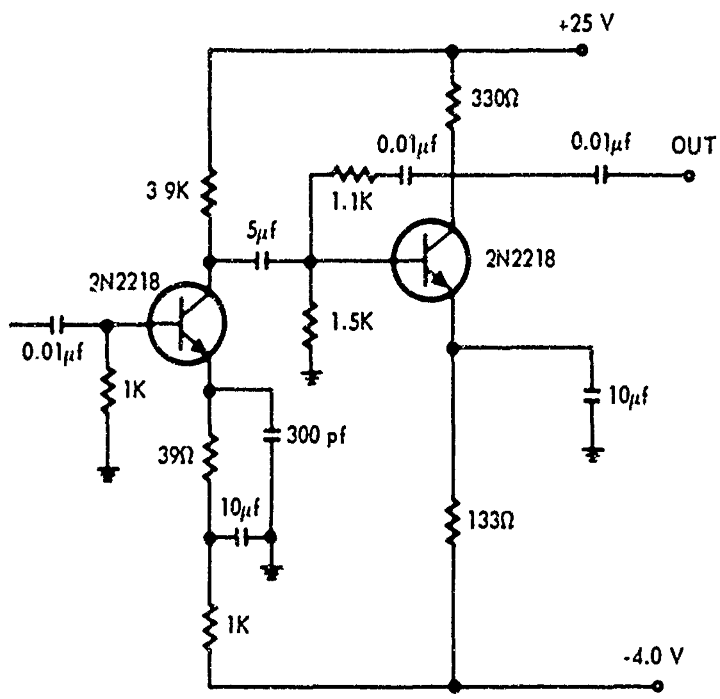


Figure 6. Amplifier circuit. Reprinted with permission of EEE from the April 1963 issue.

MIXING DEVICE

A fairly extensive search did not yield a mixing device which would yield at least ninth-order products readily detected by the monitoring receiver with the level of signals available from two oscillators at point A of figure 5. With the amplified signals, however, a choice of nonlinear elements became available for use as a mixing device. It was considered desirable that the mixing unit (1) be a small, inexpensive, and passive device; (2) generate at least ninth-order products with signal levels available; and (3) exhibit a characteristic curve with a high degree of symmetry with respect to the origin. A number of semiconductor diodes satisfy the first requirement, but the second requirement narrows the field somewhat. An IN82A diode amply satisfied the first two requirements and was chosen for the mixing device. Diodes are inherently asymmetrical devices; however, by the simple expedient of connecting two IN82A diodes in parallel with a front-to-back configuration, a device was obtained which does discriminate against even-order products to a reasonable degree -- that is, approximately to the degree exhibited by naturally occurring nonlinear devices on shipboard.

At very low signal levels the performance of the IN82A as a mixing device varied widely between individual units, but with the signal levels available from the amplifier the performance between individual units did not vary appreciably. Furthermore at very low signal levels the diode front-to-back configuration did not discriminate against even-order products to the extent desired. Since the IN82A diodes were the most efficient generators of intermodulation products found, it can be seen that an amplifier was necessary to raise the signal level applied to the mixing unit. (Although the diodes used do not have to be a matched pair, it is advisable to see that they have approximately equal front and back resistances as measured with an ohmmeter.)

POWER SUPPLY

A battery power supply was used in the SIS models built; however, any future models could contain a transistorized power supply and thus eliminate some of the drawbacks usually associated with batteries as a power supply. There is one master switch on the front panel of the simulator which controls the power supply to the oscillators and to the amplifier. There are three voltage test points on the front panel. Two of these are for the amplifier bias voltages of -4 and +25 volts. The third is the oscillator supply at +8 volts.

PHYSICAL DESCRIPTION

The 10-unit model of the SIS is completely self-contained and portable. (The only other equipment necessary to its use as a tool in the prediction of specific interfering frequencies is a monitoring receiver.) The unit is $14\frac{1}{2}$ inches long, $8\frac{1}{2}$ inches wide, and 9 inches high, including carrying handle. It weighs about 12 pounds. There are 11 toggle switches on the front panel. One of these is the master power switch. Each of the other 10 switches controls one particular oscillator output. Also on this front panel is a BNC connector which is the output of the device.

PERFORMANCE TESTS

The output of each oscillator, as mentioned previously, was set at 30 millivolts across 50 ohms at point B of figure 5. Each setting is normally made with that single oscillator on. The addition of other oscillator signals does not appreciably change the output level of the original signal.

As stated previously the harmonic output of the OT-3 and -4 oscillators in their original configuration was quite high -- in many cases within 1 or 2 dB of the level of the fundamental. Transmitter filters on shipboard deliver a relatively clean fundamental to the antennas; and since a nonlinear device generates cross products whose level falls off with increasing order, it is found that the level of cross products detectable at a receiving antenna drops off with increasing order of product. Also, even-order products are in general at a lower level than odd-order products. Because of these two facts, if the SIS is to truly simulate intermodulation-product generation on shipboard, the harmonic content of the signal from the oscillators must be at a much lower level than the level of the fundamentals, as seen from the following discussion. Suppose that each of two oscillators delivers second and seventh harmonics, for example, equal in magnitude to their fundamentals. We have $7f_1+7f_2$ equal in magnitude to $2f_1+f_2$, that is, a fourteenth-order product (fourteenth order with respect to the fundamentals, but of course only second order with respect to the seventh harmonics when *they* are considered as fundamentals) is equal in magnitude to a third-order product. This situation cannot be tolerated, since the cross-product level does not fall off with increasing order, and even-order products are not lower in level than odd-order products.

It was noted that by a suitable modification of the OT-3 and -4 oscillators the harmonic level was reduced; but it is also known that the amplifier is a nonlinear element, so the question is whether the harmonic content is low enough at the input to the diode mixer so that the output from the mixer does truly simulate the real world to a reasonable degree. Table 2 shows the intermodulation product level for two selected oscillator pairs. These values agree reasonably well with what could be expected on shipboard under certain conditions. It can be seen that the diode mixer is the controlling element for the generation of cross products. That is, the oscillator interaction and the generation of cross products within the amplifier, neither of which discriminates against even-order products, are negligible in comparison with interaction and generation of cross

TABLE 2. MEASURED VALUES OF INTERFERENCE GENERATED BY TWO PAIRS OF OSCILLATORS OF THE SHIPBOARD INTERFERENCE SIMULATOR VS AVERAGE VALUES MEASURED ON SHIPBOARD

SHIPBOARD INTERFERENCE SIMULATOR			SHIPBOARD	
ORDER OF PRODUCT	$\left(\frac{S+N}{N}\right)$* LEVELS READ ON AN R390A RECEIVER WITH AN AVERAGE NOISE FIGURE OF 6 DB IN A 4-KC/S BANDWIDTH (DB)		AVERAGE LEVELS, DB RE 1 μV	$\left(\frac{S+N}{N}\right)$ LEVELS FOR A RECEIVER WITH AN AVERAGE NOISE FIGURE OF 6 DB IN A 4-KC/S BANDWIDTH (DB) (CONVERTED FROM PRECEDING COLUMN)
	PAIR 1	PAIR 2		
2	54	56	45	70
3	63	64	60	85
4	35	33	35	60
5	39	30	40	65
6	27	30	—	—
9	10	15	10	35

*AVERAGE OF ALL READINGS OF THAT PARTICULAR ORDER OF PRODUCT WHICH LIE BETWEEN FREQUENCIES 0.5 AND 32 MC/S

products within the diode mixer, which does discriminate. Actually the level of these products at the output of the diode mixer is higher than this. But since we have limited ourselves to detectability of the ninth order and less, the product levels must be reduced. This reduces the product levels from the simulator below those actually measured on shipboard, as can be seen in table 2. However, the rate of falloff of level with increasing order of product from the simulator approximates those values measured in the real world. To achieve the values tabulated, a 20-dB, 50-ohm resistive T-pad attenuator was placed between the diode mixer and the output of the device. The attenuator not only reduces these products to a reasonable level, but knocks out the amplifier-generated noise, reduces the fundamentals impinging on the receiver to a level such that there is negligible intermodulation within the monitoring receiver, and presents a constant 50-ohm impedance to the receiver. If for certain applications a maximum cross-product order different from the ninth is desired, it can be realized by changing the value of this attenuator pad.

If, when two oscillators are on and the level of a certain-order product is noted at the monitoring receiver, a third oscillator with a frequency which does not directly

contribute to that product is turned on, it will be noted that the level of that cross product will go down. The theoretical basis for such behavior becomes rather involved. Suffice it to say that this phenomenon is noted in the real world, and thus the simulator gives an accurate presentation. The higher the order of product the more pronounced is this effect.

CONCLUSIONS

1. A shipboard interference simulator has been designed which accurately reproduces the potential frequencies of interference derived from the intermodulation between any combination of simultaneous transmitter fundamental frequencies up to a total of ten. The relationship of interference-signal magnitudes is in reasonable agreement with similar signals actually measured aboard ship.

2. The simulator is a valuable laboratory tool, since it represents an analog computer with which detailed knowledge of intermodulation phenomena can be increased. This is especially true when many more than the classic two fundamental signals are on together.

3. The simulator has proved its worth as an excellent aid in demonstrations of intermodulation interference before Naval personnel concerned with shipboard communications problems.

4. It is believed that a simulator in which the oscillators are on operational transmit frequencies can be of great help to frequency planners and users of allocated frequencies in determining and avoiding self-generated interference aboard ships.

RECOMMENDATION

A number of these simulators with 10 or more oscillators each should be made available to representative elements of the Fleet, and a realistic evaluation should be conducted to determine the acceptance or worth of this real-time technique as a means of improving Fleet communications.

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13. ABSTRACT

Analog computer-like device developed at NEL reproduces potential frequencies of interference derived from the intermodulation between any combination of simultaneous transmitter fundamental frequencies up to a total of ten. Simulator has been used in demonstrations of the seriousness of the intermodulation problem aboard ship.

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14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Crystal Oscillators - Applications						
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